

Current Producing Surface

Background of the Invention

[0001] Bandages and wound dressings are simple, familiar devices that everyone uses. At least they used to be simple. In an effort to hasten the wound healing process and reduce the risk of infection, there have been many recent efforts to redesign, or sometimes redefine, a bandage. Unfortunately, very few people have enjoyed the benefits of a “super bandage” because they are either too complex or too expensive to be widely used, let alone reach the medicine cabinets of the general public. The present invention is a method of making an improved sterile bandage that is superior to traditional bandages, but retains the simple and familiar aspects that are expected of a bandage.

[0002] The major advances in the art of wound healing are usually either improved methods for reducing infection or stimulating cell repair. It is now known that a moist wound heals faster and is less likely to scar than a dry wound, so the use of traditional bandages to keep a wound moist and protected is correct. It is also known that silver is an anti-microbial agent, so there are numerous products that deliver silver to a wound, such as Smith & NephewSM ACTICOAT 7™, Johnson & Johnson® ACTISORB™, and Bristol-Meyers SquibbSM HYDROFIBER®.

[0003] There are several problems that the prior art has encountered. Covering the wound is easy, and there are numerous products that fill that need. Delivering silver to a wound, however, has posed many difficulties because silver is a metal. How do you apply a dosage of metal into a wound? Granted, powdered silver could be sprinkled over a wound from a pepper shaker in the hope that the body will only absorb as much silver as is

needed, but excess absorption of silver will turn skin bluish-gray (although there are no known health dangers). Not surprisingly, most of the prior art does resort to using silver crystals, which have a large relative surface area, and the primary goal seems to be to deliver as much silver as possible into the wound. Colloidal silver, silver salts (e.g. silver nitrate) and silver compounds (e.g. silver sulfadiazine) have been used to make creams and ointments, which have always been popular in the field of medicine because they are easy to use and familiar.

[0004] There are numerous devices that rely on either an external electrical power source or a direct reaction between silver and another metal to generate the production of silver ions. ACTISORB™ consists of activated carbon impregnated with metallic silver. ACTICOAT 7™, developed by Dr. Robert Burrell, uses a vapor deposition technique to apply a coating of a binary alloy of silver and oxygen onto a mesh. Dr. Robert O. Becker used electricity (often from a coin battery) to produce free silver ions that penetrate into the wound tissue. Dr. William E. Crisp, et al., took the approach of amalgamating metals within a thickness of material, such as a sponge, to create a direct reaction that releases silver into a wound. Unfortunately, these prior art devices require expensive manufacturing processes, and the devices themselves can be complex and cumbersome.

Summary of the Invention

[0005] The present invention is an inexpensive method of making a pattern of spaced dissimilar conductors on a surface, visible with the naked eye, that will

spontaneously produce an electrical current when brought into contact with an electrolytic solution. In the most preferred embodiment, numerous silver and zinc conductors are painted or printed in spaced relation to one another on a biocompatible surface, such as the primary surface of a traditional bandage. High purity silver is mixed with a biocompatible binder, such as a polyacrylic ink, to form a thick liquid “silver ink”, and high purity zinc is mixed with a biocompatible binder to form “zinc ink”. The silver ink and the zinc ink can be applied to a suitable surface using a readily available screen printing apparatus, such as those used to print T-shirts. The desired conductor pattern can be printed directly onto a surface, and then cured so that the conductors are fixed in a predetermined pattern or array. Once the pattern of conductors is brought into contact with an electrolytic solution, such as wound fluid, numerous voltaic cells start generating electrical currents. Incidental to these spontaneous electrochemical reactions, silver and zinc are released into the wound.

Brief Description of the Drawings

Fig. 1 is a detailed plan view of a very basic embodiment of the present invention.

Fig. 2 is a detailed plan view of the preferred pattern of printed electrical conductors of the present invention.

Fig. 3 is an adhesive bandage using the printed pattern of Fig. 2.

Fig. 4 is a cross-section of Fig. 3 through line 3—3.

Fig. 5 is a detailed plan view of an alternate embodiment of the present invention which includes fine lines of metal ink connecting electrodes.

Fig. 6 is a detailed plan view of another alternate embodiment of the present invention having a line pattern and dot pattern.

Fig. 7 is a detailed plan view of yet another alternate embodiment of the present invention having two line patterns.

The reference numbers used in the various Figs. are as follows:

- 2 primary surface
- 3 cross-section
- 4 article
- 6 first design
- 8 spacing
- 10 second design
- 12 repetition
- 14 pattern
- 16 elastic adhesive layer
- 18 overlapping piece
- 20 back of the printed dressing material
- 22 absorbent cloth layer
- 24 fine lines

Detailed Description of the Invention

[0006] The detailed description of the present invention has been broken into two sections. The first section will teach how to make the preferred and alternate embodiments. The second section explores the theories that explain why the present invention works, but it is not necessary to understand these theories in order to make, use or otherwise benefit from the present invention. The complexities of the human body,

combined with our limited understand of the healing process, requires the realization that these theories will improve over time. Any inaccuracies or oversimplifications of the theories presented in the second section should in no way detract from the scope of the claims, which focus on the articles of manufacture and not the theories.

[0007] The preferred embodiment is a bandage, more generally a wound dressing, but the method for making a wound dressing of the present invention can similarly be applied to virtually any medical device that contacts an electrolyte of the body. Actually, the present invention can be applied to virtually any non-conductive surface that may come into contact with an electrolytic solution. The purpose of using the present invention is primarily to reduce infection and contamination, but there are additional benefits specific to wound care that are of exceptional value. These benefits will be addressed in the second section.

[0008] Over 200 years ago, in 1800, Alessandro Volta assembled the first modern battery. He sandwiched a saltwater-soaked piece of paper between a zinc disc and a silver disc, and was electrically shocked by the potential difference, or voltage, that was created by his assembly. Volta's electrochemical cell generated an electrical current because of a spontaneous oxidation-reduction reaction. In his honor, this type of electrochemical cell is called a voltaic cell, but may also be referred to as a galvanic cell. In the case of silver and zinc, electrons are transferred from zinc metal to silver ions. The oxidation half reaction of zinc metal results in the loss of two electrons to produce zinc ion, and the reduction half reaction of silver ion results in the gain of one electron to produce silver metal. The zinc electrode is the anode (negative sign) and the silver electrode is the cathode (positive sign), because the electrons flow from zinc to silver. The flow of ions

generates the electrical current, so the silver and zinc cannot directly contact each other or there will be a direct reaction with no current generated. An electrolyte, such as table salt, dissolves in water to provide an electrically conducting solution which electrically bridges the gap between the two dissimilar metals so that there is a current flow caused by the spontaneous reactions between the physically separated metals.

[0009] Ironically, the most preferred dissimilar metals used to make the preferred embodiment of the present invention (a wound dressing) are silver and zinc, and the electrolytic solution is predominantly sodium chloride in water. The unique aspect of the present invention is that the electrodes are painted or printed onto a non-conductive surface to create a pattern, most preferably an array, of voltaic cells that do not spontaneously react until they contact an electrolytic solution, such as wound fluid. The remainder of this description will use the terms “printing” with “ink”, but it is understood that the embodiments may instead be “painted” with “paints”. It is also assumed that a competent printer will know how to properly apply and cure the inks without any assistance, other than perhaps instructions that should be included with the selected binder that is used to make the ink mixtures that will be used in the printing process.

[0010] In Fig. 1, the electrodes are printed onto a desired primary surface 2 of an article 4 which, in the preferred embodiment, is that surface of a wound dressing that comes into direct contact with a wound. In alternate uses of the present invention, the primary surface is one which simply needs to be antimicrobial, such as a medical instrument, implant, surgical gown, gloves, socks, table, door knob, or other surface

that will contact an electrolytic solution, including sweat, so that at least part of the pattern of voltaic cells will spontaneously react and kill bacteria or other microbes.

[0011] The printed electrodes adhere or bond to the primary surface 2 because a biocompatible binder is mixed, into separate mixtures, with each of the dissimilar metals that will create the pattern of voltaic cells. Most inks are simply a binder mixed with pigment. Similarly, the metal inks are a binder mixed with a conductive element. The resulting metal ink mixtures are used with a common application method, such as screen printing, to apply the electrodes to the primary surface in predetermined patterns. Once the inks dry and/or cure, the patterns of spaced electrodes will substantially maintain their relative position, even on a flexible material such as cloth. To make only a few of the wound dressings of the present invention, the mixtures can be hand painted onto a common adhesive bandage so that there is an array of alternating electrodes that are spaced about a millimeter apart on the primary surface of the bandage. The paint should be allowed to dry before being applied to a wound so that the zinc ink does not mix with the silver ink, which would destroy the array and cause direct reactions that will release the elements, but fail to simulate the current of injury, as will be explained later.

[0012] The binder is any biocompatible liquid material that can be mixed with a conductive element (preferably metallic crystals of silver or zinc) to create an ink which may be applied as a thin coating to a surface. One suitable binder is a solvent reducible polymer, such as the polyacrylic non-toxic silk-screen ink manufactured by Colorcon, Inc., a division of Berwind Pharmaceutical Services, Inc. (see Colorcon's No-Tox[®] product line, part number NT28). The binder is mixed with high purity (at least 99.999% is recommended) metallic silver crystals to make the silver ink. The silver crystals, which are

made by grinding silver into a powder, are preferably smaller than 100 microns in size, or about as fine as flour. The preferred size of the crystals is about 325 mesh, which is typically about 40 microns in size, or a little smaller. The binder is separately mixed with high purity (at least 99.99% is recommended) metallic zinc powder, which has also preferably been sifted through standard 325 mesh screen, to make the zinc ink. For better quality control and more consistent results, most of the crystals used should be larger than 325 mesh and smaller than 200 mesh. Other powders of metal can be used to make other metallic inks in the same way as just described.

[0013] The ratio of metal to binder affects the release rate of the metal from the mixture. When Colorcon's polyacrylic ink is used as the binder, about 10 to 40 percent of the mixture should be metal for a longer term bandage (one that stays on for about 10 days). If the same binder is used, but the percentage of the mixture that is metal is increased to 60 percent or higher, then the release rate will be much faster and a typical bandage will only be effective for a few days. It should be noted that polyacrylic ink tends to crack if applied as a very thin coat, which exposes more metal crystals which will spontaneously react. For alternate uses, such as on an article of clothing, it may be desired to decrease the percentage of metal down to 5 percent or less, or to use a binder that causes the crystals to be more deeply embedded, so that the primary surface will be antimicrobial for a very long period of time and will not wear prematurely. Other binders may dissolve or otherwise break down faster or slower than a polyacrylic ink, so adjustments should be made to achieve the desired rate of spontaneous reactions from the voltaic cells.

[0014] When a single mass of silver ink is spaced from a single mass of zinc ink, a single voltaic cell is created if an electrolytic solution electrically connects the masses. If a single mass of silver ink is spaced from two masses of zinc ink, then two voltaic cells are created, and so on. To maximize the number of voltaic cells, a pattern of alternating silver ink masses and zinc ink masses will create an array of electrical currents across the primary surface. A very basic pattern, shown in Fig. 1, has each mass of silver ink equally spaced from four masses of zinc ink, and has each mass of zinc ink equally spaced from four masses of silver ink. The first design 6 is separated from the second design 10 by a spacing 8. The designs, which are simply round dots, are repeated. Numerous repetitions 12 of the designs result in a pattern. For a wound dressing, each silver ink design preferably has about twice as much mass as each zinc ink design. For the pattern in Fig. 1, the silver ink designs are most preferably about a millimeter from each of the closest four zinc ink designs, and visa-versa. The resulting pattern of dissimilar metal masses defines an array of voltaic cells when introduced to an electrolytic solution.

[0015] A dot pattern of ink masses, like the alternating round dots of Fig. 1, is preferred when printing onto a flexible material, such as those used for a wound dressing, because the dots won't significantly affect the flexibility of the material. The pattern of Fig. 1 is well suited for general use. To maximize the density of electrical current over a primary surface, the pattern of Fig. 2 is preferred. The first design 6 in Fig. 2 is a large hexagonally shaped dot, and the second design 10 is a pair of smaller hexagonally shaped dots that are spaced from each other. The spacing 8 that is between the first design and the second design maintains a relatively consistent distance between adjacent sides of the designs. Numerous repetitions 12 of the designs result in a pattern 14 that can be described

as at least one of the first design being surrounded by six hexagonally shaped dots of the second design. The pattern of Fig. 2 is well suited for abrasions and burns. There are, of course, other patterns that could be printed to achieve substantially the same results.

[0016] Figs. 3 and 4 show how the pattern of Fig. 2 could be used to make an adhesive bandage. The pattern shown in detail in Fig. 2 is printed onto the primary surface 2 of a wound dressing material. The back 20 of the printed dressing material is fixed to an absorbent cloth layer 22, such as cotton. The absorbent cloth layer is adhesively fixed to an elastic adhesive layer 16 such that there is at least one overlapping piece 18 of the elastic adhesive layer that may be used to secure the wound dressing over a wound.

[0017] Fig. 5 shows an additional feature, which may be added between designs, that will start the flow of current in a poor electrolytic solution. A fine line 24 is printed, using one of the metal inks, along a current path of each voltaic cell. The fine line will initially have a direct reaction, but will be depleted until the distance between the electrodes increases to where maximum voltage is realized. The initial current produced is intended to help control edema so that the wound dressing will be effective. If the electrolytic solution is highly conductive when the wound dressing is initially applied, the fine line will be quickly depleted and the wound dressing will function as though the fine line had never existed.

[0018] Figs. 6 and 7 show alternative patterns that use at least one line design. The first design 6 of Fig. 6 is a round dot, similar to the first design used in Fig. 1. The second design 10 of Fig. 6 is a line. When the designs are repeated, they define a pattern of parallel lines that are separated by numerous spaced dots. Fig. 7 uses only line designs.

The pattern of Fig. 7 is well suited for cuts, especially when the lines are perpendicular to a cut. The first design 6 may be thicker or wider than the second design 10 if the oxidation-reduction reaction requires more metal from the first conductive element (mixed into the first design's ink) than the second conductive element (mixed into the second design's ink). The lines could be dashed. Another pattern could be silver ink grid lines that have zinc ink masses in the center of each of the cells of the grid. The pattern could even be letters printed from alternating inks so that a message can be printed onto the primary surface- perhaps a brand name.

[0019] There are numerous possible creative choices of patterns, but some patterns will work better with certain combinations of inks. Because the spontaneous oxidation-reduction reaction of silver and zinc requires two silver and one zinc, the silver ink design should contain about twice as much mass as the zinc ink design. At a spacing of about 1 mm between the closest dissimilar metals (closest edge to closest edge), each voltaic cell that is in wound fluid will create approximately 1 volt of potential that will penetrate substantially through the dermis and epidermis. Closer spacing of the dots will decrease the resistance, provide less potential, and the current will not penetrate as deeply. If the spacing falls below about one tenth of a millimeter, the only realized benefit of the spontaneous reaction is that which is also present with a direct reaction- silver is electrically driven into the wound, but the current of injury is not simulated.

[0020] The remainder of this description is the second section, which focuses on the basic theories underlying why the present invention promotes wound healing. The introduction of silver metal onto a wound surface and/or into the region of damaged tissue promotes healing by direct suppression of local micro-organisms normally colonizing

the wound. Bacterial pathogens commonly include gram-positive cocci such as *Staphylococcus aureus* and group A streptococci and gram-negative bacilli such as *Pseudomonas aeruginosa*, *Escherichia coli*, and *Proteus* spp. The electrochemical nature of silver is such that it is positively charged and thus is able to bind to negatively charged sulfur moieties of the amino acids methionine and cysteine composing critical structural and enzymatic proteins utilized by bacterial cells. The effect of this binding interaction between silver and bacterial proteins is that the proteins' intrinsic chemical bonds are disrupted, causing the bacterial proteins to denature, or change 3-dimensional conformation, and thereby to be functionally ineffective in a way that is of mortal consequence to the bacterial cell.

[0021] Although it has proven to be beneficial to drive silver into the wound, that is not of primary importance in the present invention because the induced electrical current has been shown to electrochemically attract microbes to the surface of the bandage so that many of the killed microbes are removed with the bandage instead of accumulating within the wound and necessitating the phagocytic engulfment and removal by macrophages in the natural but slower process of wound healing. Of additional concern in not removing dead bacterial cells from the wound vicinity is the release of toxic enzymes and chemicals from the dead and degrading bacteria, thought to be alleviated by application of the present invention. Bacteria and other microbes are specifically drawn to the cathode (silver in the preferred embodiment) by virtue of their overall net negative charge along the created electric gradient. Because all microbes are net negatively charged, they die when they contact silver.

[0022] The most preferred material to use in combination with silver to create the voltaic cells of the present invention is zinc, which has been well-described for its uses in prevention of infection in such topical antibacterial agents as Bacitracin zinc, a zinc salt of Bacitracin. Zinc is a divalent cation with antibacterial properties of its own in addition to possessing the added benefit of being a cofactor to proteins of the metalloproteinase family of enzymes important to the phagocytic debridement and remodeling phases of wound healing. As a cofactor, zinc promotes and accelerates the functional activity of these enzymes, resulting in better, more efficient wound healing.

[0023] In a wound, the absence of the positively charged epithelium—negatively charged dermis combination which is normally observed in healthy tissue results in a deficit in the naturally occurring potential difference across the body surface. The silver-zinc voltaic cells of the preferred embodiment of the present invention recreates the physiologic current of injury important to the induction of neutrophil, macrophage and fibroblast cells essential to the healing process. In addition, the simulated current of injury stimulates regional nerve endings to promote their involvement in wound resolution.

[0024] The voltage needed at the sight of a wound has been traditionally in the range of millivolts, but the present invention introduces a much higher voltage, near 1 volt when using the 1 mm spacing of dissimilar metals already described. The higher voltage is believed to drive the current deeper into the wound bed so that dermis and epidermis benefit from the simulated current of injury. In this way, the current not only drives some silver and zinc into the wound to kill microbes, but the current also provides the necessary stimulatory current of injury so that the entire wound surface area can heal simultaneously. Without the wound dressing of the present invention, the current of injury only naturally

exists at the periphery of the wound that is within about half a millimeter of undamaged skin. That is why a wound closes from the edges in. The obvious benefit of covering the entire wound with a simulated current of injury is that the volume of skin being repaired at the same time is significantly increased.

[0025] A further benefit of a current producing wound dressing addresses the medically known fact that a wound closes faster if it is kept moist and clean. Edema should be minimized without allowing the wound surface to desiccate. The moisture balance of a wound should allow the damaged area to remain electrically conductive so that there are not areas of high resistance that block conduction of the simulated current of injury from penetrating into the tissue. Any excessive moisture and swelling creates an ideal environment for the growth of bacteria and microbes. Excess moisture that causes the damaged tissue to swell is best drawn out of the wound by being absorbed into cotton or another absorbent cloth material that will wick the excess moisture off the top of the wound surface without promoting any drying of the damaged tissue.

[0026] Finally, it is important to control the release rate of the dissimilar metals of the current producing wound dressing for two reasons, each in opposition to the other. In the preferred embodiment, the voltaic cells of the wound dressing drive the simulated current of injury deeper into the wound area if the dissimilar metals are kept separated by a predetermined distance, such that it would be undesirable to allow the silver to freely mix into the wound fluids as this would quickly result in a quenching of the electrochemical gradient and thus an extinguishing of the desired voltaic effect. On the other hand, if a predetermined quantity of silver is allowed to mix into the wound, the silver will

help prevent wound infection. (Please note that the spontaneous reactions of the voltaic cells will release elements into the wound even though the most desired method of killing microbes is at the cathodes, as already described.)

[0027] Because it is desirable to have both the current of injury and the antimicrobial effects of silver present, a compromise must be made. To achieve this optimal balance, the binder should release silver and zinc into the wound while simultaneously maintaining the simulated current of injury for the entire period of time that the bandage is left on the wound. Wound dressings that should be changed more often can have a shorter life as a current producing dressing, so the release rate of the binder can be faster. Wound dressings that are intended to be left on the wound for an extended period of time, say 10 days, should have a binder that does not dissolve or otherwise breakdown as quickly, or the percentage of binder to metallic crystals should be higher. This can be controlled by the intelligent selection of different mixture ratios and/or binder materials having longer or shorter half-lives or absorption rates.

[0028] While a preferred form of the invention has been shown and described, it will be realized that alterations and modifications may be made thereto without departing from the scope of the following claims. For example, it may be difficult, or impossible, to use a common screen printing machine to print the electrodes of the present invention onto surfaces on medical instruments, garments, implants and the like so that they are antimicrobial. It is expected that a known method of applying the paint or ink will be substituted as appropriate. Also, there are numerous shapes, sizes and patterns of voltaic cells that have not been described, but it is expected that this teaching will enable those skilled in the art to incorporate their own designs which will then be painted or printed onto a

surface to create voltaic cells which will become active when brought into contact with an electrolytic solution.